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OFFICE OF SCIENCE & TECHNOLOGY AND INTERNATIONAL

Technical Work Plan for:

NATURAL ANALOGUE STUDIES OF THE DRIFT SHADOW EFFECT

OSTI-LBNL-TWP-000002, REV 00 ICN 00

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CHANGE HISTORY

Revision Number	ICN Number	Date of Change	Description of Change
00	00	10/29/04	Initial issue.

ACRONYMS

BNSCL	Bechtel Nevada Standards and Calibration Laboratory
CD	compact disk
CFR	Code of Federal Regulations
DOE	Department of Energy
ECRB	Enhanced Characterization of the Repository Block Cross Drift
ERP	electrical resistivity probes
ESF	Exploratory Studies Facility
FY	Fiscal Year
FTP	file transfer protocol
GPS	Global Positioning System
ICN	Interim Change Notice
LA	License Application
LBNL	Lawrence Berkeley National Laboratory
OCRWM	Office of Civilian Radioactive Waste Management
OSTI	Office of Science and Technology and International
PI	Principal Investigator
PM	Project Manager
QA	Quality Assurance
QARD	Quality Assurance Requirements and Description
QIP	LBNL Quality Implementing Procedure
QMP	USGS Quality Management Procedure
RPC	Records Processing Center
SCM	Software Configuration Management
S&T	Science & Technology
TDMS	Technical Data Management System
TIP	LBNL Technical Implementing Procedure
TSPA	Total System Performance Assessment
TWP	Technical Work Plan
USGS	U.S. Geological Survey

UZ	Unsaturated Zone
YMP	Yucca Mountain Project

1. WORK SCOPE

This Technical Work Plan (TWP) supports scientific investigation activities performed for the U.S. Department of Energy (DOE) Office of Science and Technology and International (OSTI) by Lawrence Berkeley National Laboratory (LBNL) and the U.S. Geological Survey (USGS). The TWP describes an investigation of the presence and nature of drift shadows at analogue sites relevant to the disposal of high-level radioactive waste in unsaturated rock at Yucca Mountain, Nevada. The purpose of the planned scientific investigation is to improve our understanding of the drift shadow effect by performing field and laboratory tests and numerical modeling to refine conceptual and numerical models, and provide data and information for testing and building confidence in models used to predict performance of the proposed high-level radioactive waste repository at Yucca Mountain.

The activities described herein include: 1) an evaluation of analogue sites for field studies considering hydrologic similarity and logistical considerations, and an evaluation of candidate sites using modeling approaches that account for the likelihood of the development of a drift shadow and how such a shadow could be verified, 2) field and laboratory studies of drift shadow effects, 3) numerical modeling evaluation of drift shadows caused by lithophysal cavities, and 4) revision of conceptual and numerical models based on the results of the investigation.

This TWP has been prepared in accordance with the requirements specified by the Quality Implementing Procedure (QIP), OSTI-LBNL-QIP-2.2, *Planning for Science Activities.* The work is governed by the Guidance and Funds to Lawrence Berkeley National Laboratory for Tasks from the Office of Civilian Radioactive Waste Management Memorandum, dated 1/20/04. An annual progress report will be submitted to the DOE by September 2005, and a final report will be generated with input from the USGS and be submitted to DOE by September 30, 2006.

1.1 OBJECTIVES

The drift shadow is a region below an underground opening in the unsaturated zone (UZ) that is poorly connected to the natural vertically flowing percolating water because this water is deflected by the opening, and capillary suction in the fractures is insufficient to draw the water immediately inward below the opening (Figure 1). Transport of solutes and colloids in the drift shadow region tends to be dominated by diffusion. Thus, a release of radionuclides from the repository would be much slower through the drift shadow, enhancing repository performance. The main objective of this TWP is to investigate the presence and size of a drift shadow or absence of a drift shadow by performing laboratory and field tests in conjunction with numerical analysis.

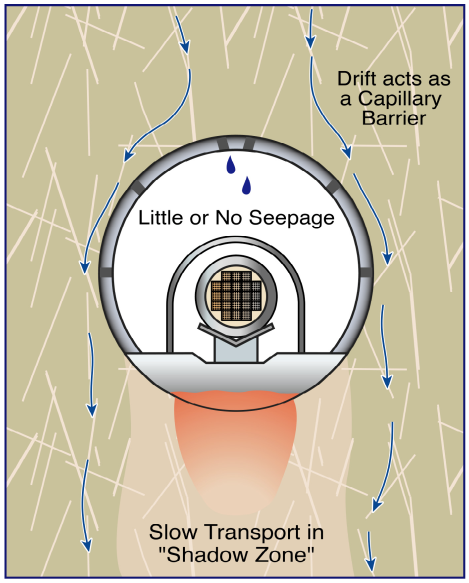

Figure 1. Drift shadow schematic.

This work includes 1) preliminary modeling to determine the effects of geometry, size, rock type, and flow parameters on the development of a drift shadow; 2) field and laboratory studies of drift shadow; 3) evaluation of drift shadows formed by lithophysal cavities at Yucca Mountain; and 4) revision of conceptual and numerical models. Field studies and analysis of fluid flow and chemical transport processes at the selected analogue site(s) will be conducted to confirm the presence or absence of drift shadow in the UZ. Acquired data will be compared with model results to provide confidence in UZ flow and transport models.

1.2 PRIMARY TASKS

This work is a collaboration between LBNL and the USGS. The OSTI-LBNL Project Manager (PM) shall have the overall responsibility for the execution of the work identified in this plan along with the OSTI-LBNL Principal Investigator (PI), the USGS PI, and LBNL/USGS technical personnel. The specific subtasks to be performed by each organization are stated in Table 1 below and a description of each task is provided in Section 2. Each organization will work under this TWP in accordance with the quality assurance (QA) procedures established by their own organization for OSTI activities.

The specific activities for drift shadow studies are contained within four tasks. The total duration of the four tasks is two years with a schedule of the tasks shown in Table 1. Decision points regarding work in the second year will be made as the work progresses. At the end of each year, a progress report will be delivered to the OSTI program at DOE. At the conclusion of the project, a final technical report will be delivered along with scientific papers submitted to peer-reviewed journals.

Table 1. Primary Tasks and Schedule for the Drift Shadow Analogue Study

Task	Title	Fiscal Year (FY)	Participants
1	Evaluate analogue sites for field studies considering hydrologic similarity and logistical considerations, and evaluate candidate sites using modeling approaches that account for the likelihood of the development of a drift shadow and how such a shadow could be verified	FY 2005	LBNL, USGS
2	Field and laboratory studies of drift shadow effects	FY2005-2006	LBNL, USGS
3	Evaluation of lithophysal cavities as analogues for seepage and drift shadow	FY 2005	LBNL, USGS
4	Revision of conceptual and numerical models for the drift shadow zone	FY 2006	LBNL

1.2.1 Task 1 – Evaluate analogue sites for field studies considering hydrologic similarity and logistical considerations, and evaluate candidate sites using modeling approaches that account for the likelihood of the development of a drift shadow and how such a shadow could be verified

This task includes:

A. Identification of parameters and attributes that are expected to favor formation of a drift shadow in the unsaturated zone and assessment of these parameters and attributes through systematic numerical simulations (LBNL)
B. Development of criteria to support drift shadow analogue site selection and guide laboratory experiments (LBNL)
C. Identification of potential drift shadow analogue sites, and collection and evaluation of hydrologic, climatic, and logistical information on these sites (LBNL, USGS)
D. Evaluation the likelihood of the presence and size of a drift shadow at selected candidate sites using numerical modeling and the best available parameters obtained from literature, site investigations, other investigations, or best estimates (LBNL).
E. Performing pre-test numerical modeling of field and laboratory tests, using location and material specific parameters and attributes. The results will aid in design and planning of experiments, identification of drift shadow detection and monitoring techniques (LBNL).

1.2.2 Task 2 - Field and Laboratory Studies of Drift Shadow Effects

For field studies this task includes:

A. Selecting field test site and design the test. Criteria for this selection will be derived in part from the results of Task 1 modeling (LBNL, USGS).

B. Performing measurements of needed properties. Drill boreholes for air permeability, water injection, sample collection, and monitoring, and perform needed tests (LBNL, USGS)

Passive drift shadow evaluation

For studies of a drift shadow site that developed as a result of existing processes (no active water injection), additional characterization will be needed to calibrate conceptual and numerical models. To investigate the drift shadow, samples will be obtained using appropriate techniques (e.g. removing rock samples, coring rock) and evaluated in the field or laboratory, and data evaluated (LBNL, USGS).

Active drift shadow evaluation

If active tests (water injection tests) are needed, this includes:

A. Measuring air permeability (LBNL)
B. Setting up test bed as needed for active tests. Several alternative tests are described below (LBNL).
C. Applying a tracer to the drift bottom as needed (LBNL)
D. Injection of test water containing appropriate tracers (LBNL)
E. Monitoring flow and seepage around and in drift or drift analogues (LBNL)
F. Carefully excavating a region around and below drift analogues and observe flow paths if applicable (for smaller, accessible drift analogues) (LBNL, USGS)
G. Performing chemical analysis of rock and water samples to evaluate the flow diversion and drift shadow zones as needed (LBNL, USGS)
C. Evaluation of data (LBNL, USGS)

For laboratory studies (LBNL) this task includes:

A. Construction of a test apparatus
B. Introduction of water containing appropriate tracers
C. Monitoring flow and seepage using techniques such as tensiometry, psychrometry, electrical resistance, and x-ray attenuation
D. Evaluation of data

1.2.3 Task 3 - Evaluation of Lithophysal Cavities as Drift Analogues for Seepage and Drift Shadow

This task includes:

A. Numerical modeling to evaluate the presence and size of drift shadow below lithophysal cavities at Yucca Mountain (LBNL)
B. Field characterization of lithophysal cavities (USGS)
C. Chemical analysis of secondary minerals around lithophysal cavities (USGS)

1.2.4 Task 4- Revising Conceptual and Numerical Models for the Drift Shadow Zone

This task will include the following:

A. Revision and refining of the existing conceptual and numerical models of flow and transport around a drift shadow using the results of Tasks 1 through 3 (LBNL)
B. Extension of conceptual models to flow and transport models of Yucca Mountain (LBNL)
C. Preparation of reports and documentation suitable for publications (LBNL, USGS)

1.3 ACCURACY, PRECISION, AND REPRESENTATIVENESS OF RESULTS

The level of accuracy, precision, and representativeness of results for each activity will be determined by the LBNL/USGS PIs responsible for the tasks associated with this TWP. In many cases, these determinations will be stated in technical procedures. If not, the PI will base decisions on information provided by discussions with collaborators, from literature searches, and by expert judgment gained through experience. Decisions will be documented in the related scientific notebooks.

The accuracy, precision, and representativeness of the results of conceptual and numerical models of flow and transport around a drift shadow, and how these are determined will be addressed in initial progress reports and the final technical report generated as part of these activities. Uncertainties associated with the models are a function of the specific application, and will be discussed in the final report.

Numerical representation of a real world system involves discretization of a model volume into a large number of elements, with each element assigned the necessary attributes or properties. For large models, the necessary attributes or properties are known at only few locations within the model domain. Errors may result during conceptual and numerical model development from the simplification of the infinitely complex natural system into a final set of (fairly coarse) elements, from erroneous conceptualization of a physical system, or inaccuracy in describing physical processes. Limitations of the software used to model flow and transport around the drift shadow may also create a potential source of error. This error is addressed in the software qualification. Software expected to be used will predominantly be qualified software obtained from the Yucca Mountain Project (YMP) Software Configuration Management (SCM) that has been qualified in accordance with applicable YMP procedures. Any newly developed or modified existing software will be qualified in accordance with OSTI-LBNL QIP-SI.0, *Software Management* or USGS Science and Technology (S&T) Quality Management Procedure (QMP) S&T-QMP-SI.01, *Software Management*, as appropriate.

2. SCIENTIFIC APPROACH OR TECHNICAL METHODS

The scientific approach to be used for each activity is described below. Approaches and methods used will depend on factors that may vary or change during the work process.

2.1 WORK ACTIVITIES

2.1.1 Task 1 - Evaluate analogue sites for field studies considering hydrologic similarity and logistical considerations, and evaluate candidate sites using modeling approaches that account for the likelihood of the development of a drift shadow and how such a shadow could be verified

Intended Use and/or Purpose of Activity/Product

The purpose of this task is to perform numerical simulations to identify key parameters and attributes that determine the formation of drift shadow, identify and evaluate sites that are expected to have drift shadows, gather information on field sites including hydrologic and logistical parameters, and identify methods by which the drift shadow can be quantified. By varying the model parameters and attributes over wide ranges, the results of this task will help LBNL staff in selecting and designing field and laboratory studies as described in Section 2.1.2 below.

Responsible Organization(s)

LBNL will perform this task in collaboration with the USGS. LBNL will perform all modeling in this task, both organizations will identify and gather information on potential sites, and identify criteria for selection of a field test site.

Scientific Approach

The general approach of modeling drift shadow effects will be similar to the study of Houseworth et al. (2003). Initial modeling studies will assess the roles and sensitivities of various parameters and attributes (including drift size and geometry, formation heterogeneity, hydrologic properties, and percolation flux) in the development of a drift shadow. Subsequent modeling studies will utilize best available parameters and attributes of selected field test sites and laboratory models to identify the conditions that will result in the development of drift shadow. These results will be used to determine whether the drift shadow may be identified more easily at a field site where processes have occurred over a long duration, or to design field and laboratory tests that are expected to develop detectable drift shadows within a reasonable period. The results of numerical modeling will also be used to identify the depths below a drift analogue that should be investigated, and to provide information on techniques that could be used to identify the drift shadow.

Included within the modeling studies mentioned above, three specific cases may be investigated depending on the results of preliminary modeling and logistical considerations. The first is the Alcove 8-Niche 3 test, where tracer-bearing water has been injected in Alcove 8, and recovered in trays in Niche 3, approximately 20 meters below. A drift shadow below Niche 3 will be modeled. The second more specific case is a borehole drilled above the ceiling of an existing mined drift, cave, or lava tube, with a series of monitoring boreholes drilled strategically below the drift. Water would be supplied to the top borehole, and detected in the boreholes below. The third more specific case is a series of drift analogues mined into the wall of an existing mined drift, cave, or lava tube, with water supply boreholes drilled above the each drift analogue, and monitoring boreholes drilled below each.

Information on mined drifts, caves, and lava tubes will be collected and evaluated to help determine potential test sites. This information will be collected from the literature, internet searches, available databases, and interviews with knowledgeable individuals. The information will be evaluated using criteria developed in the modeling, and by considering safety and logistical considerations.

Technical Methods
In this task attributes and parameters of field and laboratory test sites will be defined through numerical simulation. Numerical models that represent field and laboratory test sites will be developed using the numerical simulators iTOUGH2, TOUGH2 (contained in iTOUGH2) and T2R3D, along with other utility software listed in Table 6. Simulations with these models will assist in identifying the conditions and scenarios that favor the formation of drift shadow. The simulations will also help evaluate the role of factors such as drift geometry and size, ventilation, depth of overburden, rock types, fracture density, secondary minerals in fractures and/or cavities, and other features.

Codes expected to be used in this work have been qualified under the YMP. Modification of these codes is not expected. However if it is necessary, modification shall be performed in accordance with OSTI-LBNL-QIP-SI.0.

Information collected will be evaluated by assigning values to criteria developed, and ranking sites based on this evaluation. The magnitude of the weighting factors will be recorded in a scientific notebook.

Data reduction
Modeling data will be reduced and plotted using qualified or commercial-off-the-shelf software. Electronic data shall be managed in accordance with OSTI-LBNL-QIP-SV.0, *Management of OSTI-LBNL Electronic Data.*

Recording results
Results of model runs and comparisons with data will be recorded in scientific notebooks in accordance with OSTI-LBNL-QIP-SIII.0 *Scientific Notebooks*.

Provisions for handling unexpected results, unanticipated conditions, or the occurrence of off-normal events during testing
Unexpected results may occur in the numerical modeling and there may be conflicting data for model input parameters. Unexpected results in the numerical modeling shall be investigated by thoroughly reexamining the input data to verify its correctness. Reexamination of the data shall be documented in a scientific notebook. Conflicting information on candidate parameters will be further investigated and evaluated and professional judgment used to establish and select the most appropriate values.

2.1.2 Task 2 - Field and Laboratory Studies for Drift Shadow Effects

Intended Use and/or Purpose of Activity/Product
The purpose of this task is to perform field and laboratory tests to measure the extent of drift shadows under reasonably constrained conditions so that comparison with model results is possible. The planned study has the potential to determine whether the drift shadow concept can be confirmed through field and laboratory experiments. Results from this proposed work will provide information to revise numerical models and will increase confidence in repository performance assessment.

Responsible Organization(s)
Site characterization will be performed by LBNL, with input from the USGS. Sample collection will be performed by the USGS with input from LBNL. Chemical analyses of water and rock samples will be performed by the USGS.

Scientific Approach
A field site will be selected for investigation of the drift shadow concept based on the results of Task 1 and available site-specific information, safety, logistics, availability for testing, and access. At the selected test bed site, either an evaluation of a naturally-occurring drift shadow will be investigated using hydrologic and geochemical tools (passive test), or water injection tests will be conducted and rock and water samples will be collected for analysis to determine the presence and size of the drift shadow (active test). At the laboratory scale, experiments will be conducted to support the field study and verify the numerical modeling simulations.

Technical Methods
Field test – Passive or Active
A systematic geological and hydrological characterization will be performed at the scale of the test. At the selected site, detailed geologic mapping, sketches of features, and measurement of fracture orientations, lengths and apertures will be performed as needed for site characterization. Appropriate rock and water samples will be collected and analyzed to evaluate the site. A passive or active evaluation will then be performed.

Passive Evaluation

If the results of Task 1 indicate the presence of a drift shadow resulting from long-duration normal conditions at a site, and that this might be detectable using hydrologic or geochemical tools, then samples of rock and water will be obtained from the model-specified locations in order to infer the extent of the drift shadow. Site hydrological characterization will be performed if needed for development of conceptual and numerical models. Sampling will be performed by both LBNL and the USGS, and chemical analyses will be performed by the USGS.

Active Evaluation

Three types of alternative field tests are described below. The results of Task 1 will be used to select the most appropriate test.

The first alternative for a drift shadow evaluation is the Alcove 8-Niche 3 Test bed. In the Alcove 8-Niche 3 Test, water with tracers has been introduced (and is currently being introduced) into a fault or onto the floor of Alcove 8, which overlies Niche 3 by about 20 m (Figure 2). Water has been captured in Niche 3 in trays suspended below the niche ceiling, thus flow has progressed to the level of Niche 3. This collected water was not allowed to percolate through the drift floor. Also, ventilation in the drift has removed water from the rock near the drift. This test has been ongoing for some time and has established conditions that would presumably have caused a drift shadow to form below Niche 3 and the ESF near Niche 3. To locate the extent of the drift shadow at this location, up to 6 boreholes will be drilled below Niche 3, and core retrieved. The retrieved core will be examined and analyzed for the presence of the tracers applied in the Alcove 8-Niche 3 Test that were not present in the construction water. The presence of these tracers indicates that water from the Alcove 8-Niche3 Test has flowed in the region that the sample was collected. Additionally, monitoring instruments including electrical resistivity probes and psychrometers will be installed in the boreholes to monitor changes as the system returns to normalcy following drilling. This is expected to take one to two months. The exact number of boreholes and their orientation will be determined by evaluating the results of preliminary numerical modeling, so as to use the model as a guide for locating the drift shadow.

The second alternative would be to drill up to 6 boreholes at strategic locations below and one borehole above a drift or cave at the selected analogue site (Figure 3a). Borehole sensors including ERPs and psychrometers will be installed in the boreholes at a desired spatial resolution. Water will be injected into the borehole above the crown and the lower boreholes will be monitored for water arrival time.

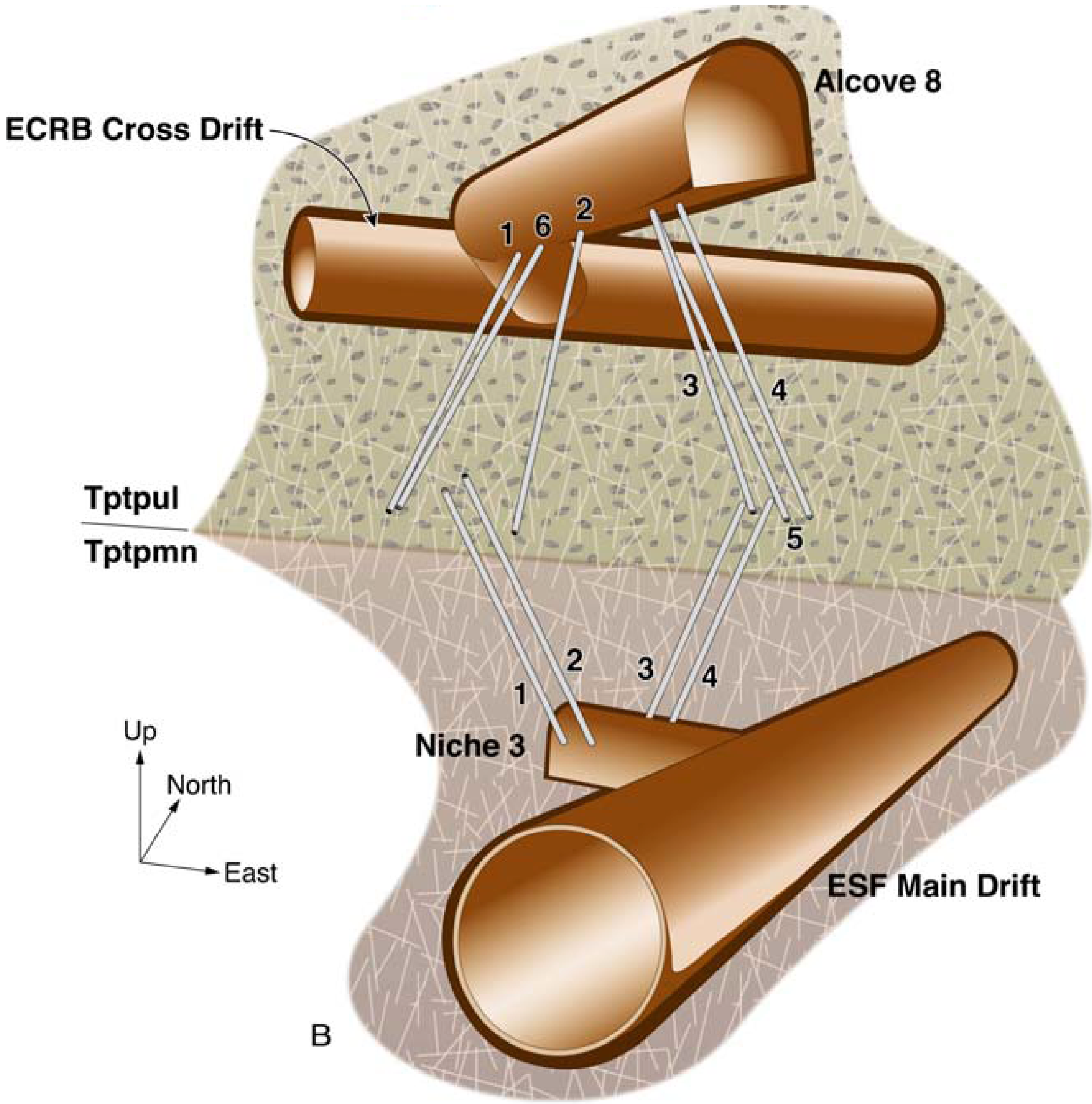

Figure 2. Alcove 8-Niche 3 Test Bed.

The third alternative includes mining a number of drift analogues having various sizes and/or shapes into the wall at the selected site. Boreholes will be installed above the drift analogues for introduction of tracer-bearing water, and below the analogues to detect the flow (Figure 3b). The sizes of the drift analogues and the locations of the monitoring boreholes would be determined in Task 1. Following water injection, the region will be mined back to observe the location of the deposited tracer.

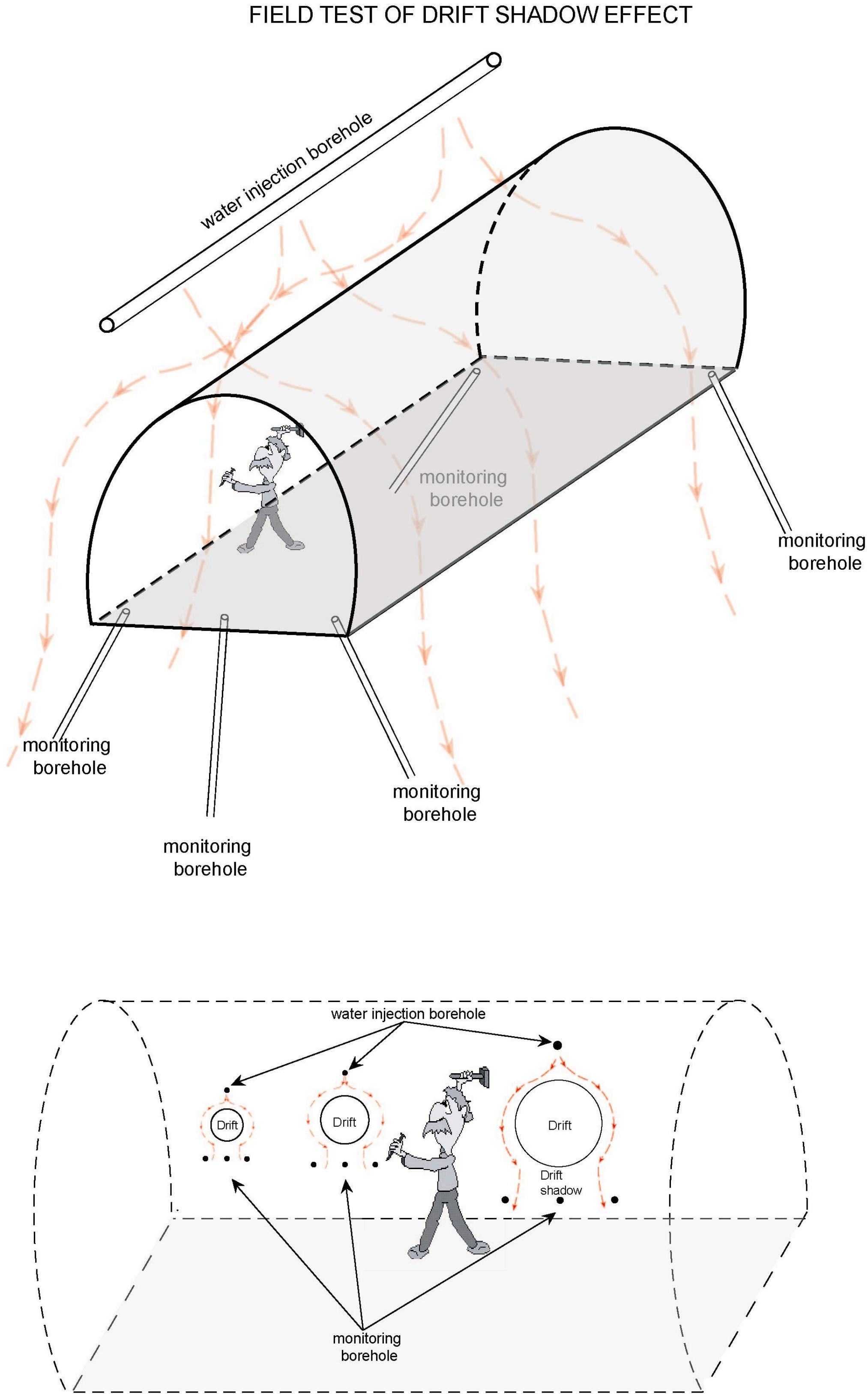

Figure 3. Field test concepts including a. drift-scale evaluation, and b. drift analogues evaluation.

For both large and small-scale field tests, boreholes will be placed above and below the drift to measure air permeability, introduce water, and measure water content changes. For the water injection, appropriate tracers or dyes will be used to allow visualization of the flow path. The water flow will be monitored and controlled during the test. Flow and seepage around and in the drift will be monitored. Test durations will be estimated from the results of numerical simulations and from observations of fluid flow made during the tests. After the water injection has been completed, careful excavation around and below the drift will provide information on flow path location and drift shadow extent.

Appropriate rock and water samples will be collected for analysis in order to determine the size and the presence of the drift shadow features at selected drift locations. Data collected from field tests will be used to verify the model and model parameters. Additional analytical methods may be considered, and will be documented in the scientific notebook.

Laboratory experiments

A number of laboratory tests will be performed to investigate key drift shadow parameters identified in Task 1. The experiments will identify how the parameters and boundary conditions defined by modeling would affect flow diversion. A test apparatus will be constructed using natural or man-made material with dimensions for the experiment drift size, geometry, distance of water injection and other experimental parameters extracted from the numerical modeling. A conceptual laboratory experiment is illustrated in Figure 4. The faces of selected material will be sealed with acrylic or another type of material suitable for the experiment. Water with tracer or dye will be injected above the drift distributed along the top boundary, or at a point or line. Water flow and seepage will be monitored. During the experiment water potential will be measured at a number of locations with a tensiometer. Change in saturation will be measured with electrical resistivity probes (ERPs) and humidity with psychrometers. The experiment will be monitored and visualization of water flow may be recorded and analyzed.

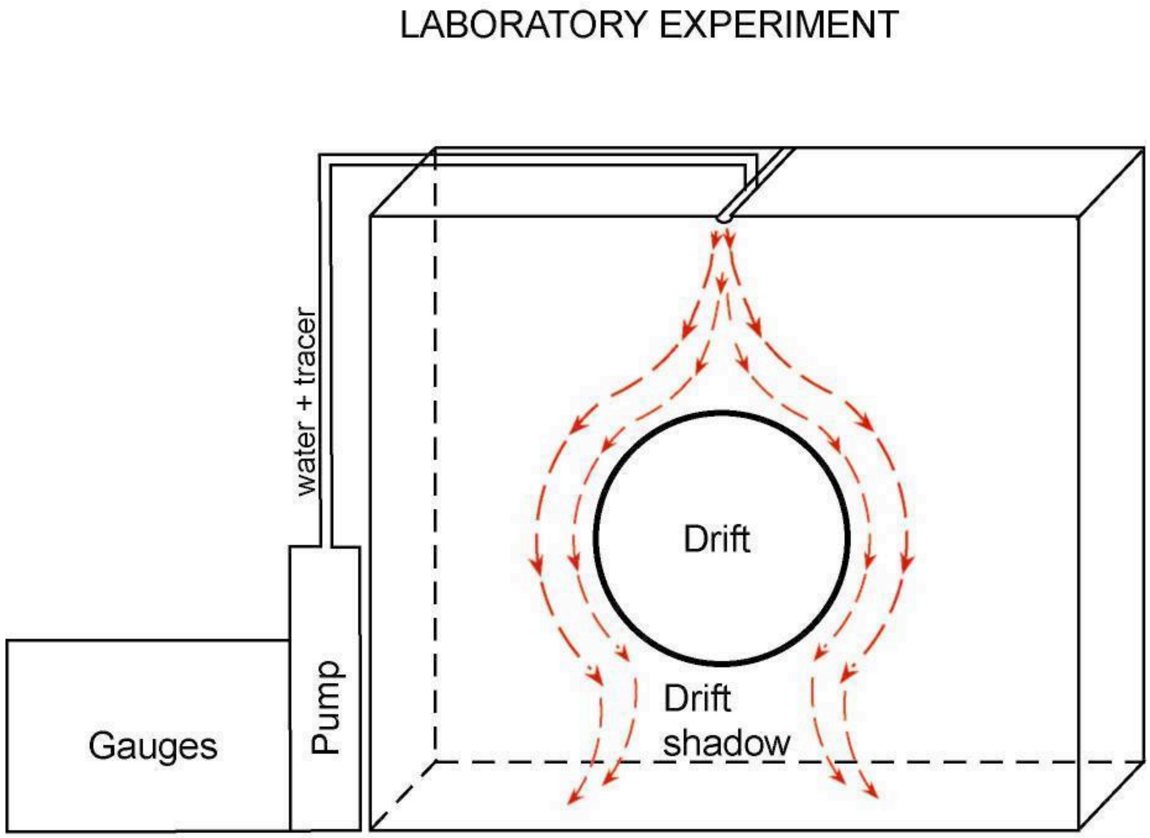

Figure 4. Schematic of laboratory experiment.

Data reduction
The interpretation of the data and methods for data reduction will be recorded in a scientific notebook. Data including tables of values, photomicrographs, and other forms will be collected in this task. Obtained data will be of various forms, and will be reduced by various methods such as assigning values to different characteristics based on calibrations to allow a numerical comparison. Spreadsheets may be used to aid this process.

Recording results
Data will be recorded in scientific notebooks following OSTI-LBNL-QIP-SIII.0 and S&T-QMP-SIII.01, as applicable. Electronic data files will be recorded following OSTI-LBNL-QIP-SV.0, and USGS Supplement V protocols described below.

> **For work done by the USGS,** electronic databases are maintained on work stations/personal computers. The databases are backed up on a fixed schedule, and whenever blocks of new data are added. Backed-up files are stored on fixed and removable magnetic media and removable optical media. Backup media are kept in secure areas remote from the workstations/personal computers. Backup is also provided by hard copies of original raw data and by laboratory notebooks. Completeness and accuracy of data input are assured through multiple checking steps. A final check is

performed by retrieving data from the database and physically checking it against the original input records. Any errors are corrected and the records are rechecked after correction. Records of this checking process are maintained. Computers used for processing and storing OSTI information will be password protected.

Typical storage media include computer hard drives, compact disks (CDs), floppy disks, tape, Zip disks and file servers all maintained in the protection of an indoor environment. These media are considered adequate for data storage for the typical retention time (e.g., up to one year) prior to database input. The computer operating system, including server, where the data are stored has adequate process controls such that disk transfer problems are obvious to the user, reporting a caution or warning if the transfer to disk is incorrect. For CDs, floppy disks, tapes, Zip drives, etc., the media have been found to retain retrievable and accurate data for several years.

Information transfers from one computer to another will be performed by magnetic media, internet, or local network, using file transfer protocol (FTP) or attachments to e-mail on the same system. These transfer methods are quite dependable and generally error free. In most cases, such transfers are between computers that use a common operating system and storage format. In these cases, the name, date, and file size will be visually checked. ASCII files will also be verified by visual comparison of the data.

The TDMS or an internal USGS database will be utilized for storage, retrieval and maintenance of electronic data that support technical products. Data may be transferred and/or subsequently retrieved from these databases and incorporated within the technical product. The accuracy, completeness, and integrity of the data shall be verified through the review and checking requirements of USGS S&T-QMP-SIII.03 *Data Collection and Review*.

Equipment will be calibrated and controlled in order to prevent loss or damage of data by LBNL following OSTI-LBNL-QIP-12.0, *Control of Measuring and Test Equipment and Calibration Standards,* and USGS following S&T-QMP-12.01, *Control of Measuring and Test Equipment*, respectively. Field sampling for geological and hydrological characterization shall be documented by LBNL according to OSTI-LBNL-QIP-SII.0, *Documenting Sample Control*, and USGS according to S&T-QMP-SII.01, *Identification & Control of Samples*, respectively.

Provisions for handling unexpected results, unanticipated conditions, or the occurrence of off-normal events during testing
In the case that observed values or instrumental behavior differ substantially from expected results, the instrument and/or data acquisition system will be inspected. If unexpected results are not related to equipment or instrumentation error, scientists will modify scientific approaches (i.e., sampling location, direction of drilling) accordingly and record events in their scientific notebook following OSTI-LBNL-QIP-SIII.0 and S&T-QMP-SIII.01, as applicable. Equipment found to be malfunctioning will be repaired or replaced per OSTI-LBNL-QIP-12.0, or S&T-QMP-12.01, as applicable.

2.1.3 Task 3 - Evaluation of Lithophysal Cavities as Drift Analogues for Seepage and Drift Shadow

Intended Use and/or Purpose of Activity/Product
Lithophysal cavities in an unsaturated zone provide a natural setting for the formation of drift shadow. The purpose of this task is to investigate the presence and extent of drift shadow below lithophysal cavities through numerical modeling and field observations. The results of this activity will be used by the USGS for assessment of drift shadow below lithophysal cavities using geochemical signatures.

Responsible Organization(s)
LBNL and USGS will collaborate in field characterization of the lithophysal cavities. Numerical modeling of the flow around lithophysal cavities will be performed by LBNL. Sampling and subsequent geochemical analyses will be performed by the USGS according to S&T-USGS-SIP-03, *Testing the Concept of Drift Shadow*.

Scientific Approach
Lithophysal cavities at Yucca Mountain provide the opportunity to evaluate the time-integrated effects of cavities on flow and transport processes in the same environment as the proposed repository. The deposition of secondary minerals such as calcite and opal on the floors of some lithophysal cavities may have sealed the floor of the cavity, causing drift shadow effects. Detailed study of these cavities and the rock surrounding them, along with flow and transport modeling, will help determine whether or not a drift shadow developed beneath these features.

Technical Methods
Numerical models of the geologic units containing lithophysal cavities will be developed using iTOUGH2. Appropriate hydrogeological parameters of the unit will be obtained from previous studies of the formation. Simulations of unsaturated flow around generic lithophysal cavities will be performed to understand and constrain the conditions necessary for formation of a detectable drift shadow beneath lithophysal cavities. The results of these preliminary numerical modeling activities will help the USGS to focus their geochemical studies on the most likely drift shadow regions. Subsequent location-specific simulations using parameters appropriate for the geologic unit containing lithophysal cavities at Yucca Mountain and attributes of selected lithophysal cavities (e.g., size and geometry of cavities) will be performed to evaluate the extent of drift shadows below lithophysal cavities. If the numerical evaluation identifies a sufficient drift shadow effect, a physical evaluation of the drift shadow will be performed by geochemical analyses of rock matrix and fracture samples.

Data reduction
Multiple types of data will be generated in this task including tables of values, photomicrographs, and other forms. The interpretation of the data and methods for data reduction will be recorded in the scientific notebook.

Recording results
Data will be recorded by LBNL and USGS in scientific notebooks following OSTI-LBNL-QIP-SIII.0 and S&T-QMP-SIII.01 respectively, and electronic data files following OSTI-LBNL-QIP-SV.0, or USGS protocols described in Section 2.1.2, respectively. Equipment will be calibrated and controlled to prevent loss or damage of data by LBNL and USGS following OSTI-LBNL-QIP-12.0, or S&T-QMP-12.01, respectively. Field sampling for geological and hydrological

characterization shall be documented by LBNL and USGS according to OSTI-LBNL-QIP-SII.0 and S&T-QMP-SII.01, respectively.

Provisions for handling unexpected results, unanticipated conditions, or the occurrence of off-normal events during testing
Unexpected results may occur in the numerical modeling and chemical analyses of samples. Unexpected results in the numerical modeling shall be investigated by thoroughly reexamining the input data to verify its correctness. Reexamination of the data shall be documented in the scientific notebook. Unexpected results of chemical analyses shall be investigated by examining the sample history and analysis. If the analysis of sample history does not reveal an explanation for the unexpected results and if a duplicate sample is available and has not been analyzed, the duplicate shall be analyzed for verification purposes. The steps taken in reexamination of the analyses and sample history shall be documented in the scientific notebook.

2.1.4 Task 4 – Revision of Conceptual and Numerical Models for the Drift Shadow Zone

Intended Use and/or Purpose of Activity/Product
The purpose of this task is to refine the existing conceptual and numerical model of the drift shadow based on the results of Tasks 1 – 3.

This planned study (Task 1 – 4, altogether) has the potential to demonstrate that the performance of natural systems at Yucca Mountain could be significantly greater than previously estimated by the YMP. Results from this proposed work will increase confidence in repository performance and enhance scientific defensibility of total system performance assessment (TSPA) for License Application (LA). This study also has the potential to open up a new research area that is critical not only for the Yucca Mountain site, but also for the other unsaturated geological disposal sites under consideration worldwide. Therefore, the research is important for maintaining U.S. scientific leadership in nuclear waste management and for increasing acceptance of Yucca Mountain as a suitable site by both the public and the scientific community

The research results will be published in a final report as described in the Guidance and Funds to Lawrence Berkeley National Laboratory for Tasks from the Office of Civilian Radioactive Waste Management Memorandum, dated 1/20/04.

Responsible Organization(s)
This task will be performed by LBNL.

Scientific Approach
Differences and similarities between the model simulations and field and laboratory observations will be used to identify the strengths and weaknesses of the conceptual and numerical models used for the simulations. Remedies to the weaknesses and improvements to the conceptual and numerical models will be considered and tested against the observations.

Technical Methods
The results of numerical simulations performed using best available location-specific parameters and attributes will be compared with field and laboratory observations from Tasks 2 and 3. Differences between the simulations and observations (if any) will be carefully scrutinized and

explained. If the differences are determined to arise from deficiencies of the conceptual or numerical models, appropriate improvements will be considered and implemented. The revised models will be tested by comparison with the observations. The refined conceptual model can then be applied to flow and transport models for the Yucca Mountain system.

Data reduction
Modeling data will be reduced and plotted using qualified or commercial-off-the-shelf software. Electronic data shall be managed in accordance with OSTI-LBNL-QIP-SV.0.

Recording results
Results of model runs and comparisons with data will be recorded in a scientific notebook in accordance with OSTI-LBNL-QIP-SIII.0.

Provisions for handling unexpected results, unanticipated conditions, or the occurrence of off-normal events during testing
Unexpected results may occur in the numerical modeling. There may be conflicting data for model input parameters. Unexpected results in the numerical modeling shall be investigated by thoroughly reexamining the input data to verify its correctness. Reexamination of the data shall be documented in a scientific notebook. Conflicting information on candidate parameters will be further investigated and evaluated and professional judgment used to establish and select the most appropriate values.

2.2 ADDITIONAL MODELING AND SCIENTIFIC ANALYSIS ACTIVITIES

This is not applicable to the preliminary modeling activities described in Task 1, nor the laboratory and field tests described in Task 2. These modeling activities will be conducted and the results will be presented in a final report and in peer-reviewed journals as described in the Guidance and Funds to Lawrence Berkeley National Laboratory for Tasks from the Office of Civilian Radioactive Waste Management Memorandum, dated 1/20/04 for Fiscal Year 2004. Modeling activities conducted in Tasks 3 and 4 will be performed using Level I Validation guidelines according to OSTI-LBNL-QIP-2.2 Attachment 2, because the intended use of the model is to gain confidence in unsaturated zone flow.

The purpose of this work is to determine the presence or absence of a drift shadow in a situation where one would be indicated by preliminary models. Additionally, the field and laboratory testing performed in Task 2 will provide data for comparison to and corroboration with the model. The purpose of Task 4 is to review and revise the conceptual model of the drift shadow if necessary. Model validation will be performed in Task 4 by comparing the predicted and measured presence of a drift shadow, and the model will be considered acceptable if a drift shadow is measured at a location where one is predicted.

3. INDUSTRY STANDARDS, FEDERAL REGULATIONS, DOE ORDERS, REQUIREMENTS, AND ACCEPTANCE/COMPLETION CRITERIA

This work is governed by the Guidance and Funds to Lawrence Berkeley National Laboratory for Tasks from the Office of Civilian Radioactive Waste Management Memorandum, dated 1/20/04.

3.1 DIRECTLY APPLICABLE STANDARDS, CODE OF FEDERAL REGULATIONS, DOE ORDERS, AND REGULATORY REQUIREMENTS

Not applicable. No directly applicable standards, Federal Regulations, DOE Orders, or regulatory requirements apply.

3.2 ACCEPTANCE/COMPLETION CRITERIA

Data resulting from field and laboratory activities described in this TWP and USGS collaborative task should be adequate to (1) evaluate flow diversion in the analogue site, (2) verify the presence of drift shadow (3) revise and refine existing conceptual and numerical models of flow and transport as applied to the analogue sites and, (4) define potential application of the drift shadow to the Yucca Mountain flow and transport modeling around emplacements drifts.

4. IMPLEMENTING DOCUMENTS

The following tables include key OSTI-LBNL procedures that apply to the activities in this TWP conducted by LBNL (this list may not be inclusive). If any of the implementing procedures is superseded (or revised), the work will be accomplished in accordance with the new or revised procedure.

Table 2. OSTI-LBNL Quality Implementing Procedures (QIPs)

OSTI-LBNL-QIP-1.0	*OSTI-LBNL Organizational Structure*
OSTI-LBNL-QIP-2.0	*Indoctrination and Training of Personnel*
OSTI-LBNL-QIP-2.1	*Establishment and Verification of Required Education and Experience of Personnel*
OSTI-LBNL-QIP-2.2	*Planning for Science Activities*
OSTI-LBNL-QIP-2.3	*Surveillances*
OSTI-LBNL-QIP-4.0	*Procurement Document Control*
OSTI-LBNL-QIP-5.0	*Preparing the Quality Assurance Plan and Quality/Technical Implementing Procedures*
OSTI-LBNL-QIP-6.0	*Controlled Documents*
OSTI-LBNL-QIP-6.1	*Document Review*
OSTI-LBNL-QIP-7.0	*Control of Purchased Services*
OSTI-LBNL-QIP-12.0	*Control of Measuring and Test Equipment and Calibration Standards*
OSTI-LBNL-QIP-15.0	*Nonconformances*
OSTI-LBNL-QIP-16.0	*Condition Reporting and Resolution*
OSTI-LBNL-QIP-17.0	*Records Management*
OSTI-LBNL-QIP-18.0	*Quality Assurance Audits and Management Assessments*
OSTI-LBNL-QIP-SI.0	*Software Management*
OSTI-LBNL-QIP-SII.0	*Documenting Sample Control*
OSTI-LBNL-QIP-SIII.0	*Scientific Notebooks*
OSTI-LBNL-QIP-SIII.1*	*Technical Reports*
OSTI-LBNL-QIP-SIII.2*	*Model Reports*
OSTI-LBNL-QIP- SIII.3	*Submittal and Incorporation of Data to the Technical Data Management System*
OSTI-LBNL-QIP- SIII.4	*Qualification of Unqualified Data*
OSTI-LBNL-QIP-SV.0	*Management of OSTI-LBNL Electronic Data*
* To be invoked by management direction	

Table 3. OSTI-LBNL Technical Implementing Procedures (TIPs)

OSTI-LBNL-TIP/HT-4.0	*Balance Calibration*

Additional Technical Implementing Procedures (TIPs) will be developed as needed to address specific topics in accordance with OSTI-LBNL-QIP-5.0, *Preparing the Quality Assurance Plan and Quality/Technical Implementing Procedures*.

The following tables include key USGS S&T procedures that apply to the activities conducted by USGS in this TWP (this list may not be inclusive). If any of the implementing procedures is superseded (or revised), the work will be accomplished in accordance with the new or revised procedure. If needed, additional technical procedures will be developed in accordance with S&T-QMP-5.01, *Preparation of Technical Procedures*.

Table 4. S&T-USGS Quality Management Procedures (QMPs)

S&T-QMP-1.01	*Organization Procedure*
S&T-QMP-2.01	*Training of Personnel*
S&T-QMP-2.02	*Personnel Qualifications*
S&T-QMP-2.04	*Review Procedure*
S&T-QMP-4.01	*Procurement Actions*
S&T-QMP-4.02	*Control of Agreements*
S&T-QMP-5.01	*Preparation of Technical Procedures*
S&T-QMP-5.02	*Development & Maintenance of Quality Management Procedures*
S&T-QMP-6.01	*Document Control*
S&T-QMP-12.01	*Control of Measuring and Test Equipment*
S&T-QMP-16.01	*Quality Deficiency Reporting and Resolution*
S&T-QMP-17.01	*QA Records Management*
S&T-QMP-SI.01	*Software Management*
S&T-QMP-SII.01	*Identification & Control of Samples*
S&T-QMP-SIII.01	*Scientific Notebooks*
S&T-QMP-SIII.03	*Data Collection and Review*
S&T-QMP-SIII.04	*Interpretive Reports*

Table 5. YMP-USGS Technical Procedures

YMP-USGS-GCP-02	Labeling, Identification, and Control of Samples for Geochemistry and Isotope Geology
YMP-USGS-GCP-38	Determination of Chemical Composition by Inductively Coupled Plasma Mass Spectrometry
YMP-USGS-GCP-25	Determination of Chemical Composition by Energy Dispersive X-Ray Fluorescence Spectrometry
YMP-USGS-HP-202	Analysis of Water Samples for Anion, Cation and Silica Concentrations by Ion Chromatography
YMP-USGS-GP-27	Trench Wall and Natural Outcrop Sampling for Coordinated Studies
YMP-USGS-HP-300	Extraction of Pore Water by High Centrifuge Method Manual Operation

5. EQUIPMENT

The annual progress reports will be prepared using project standard desktop computers.

5.1 FIELD EQUIPMENT

The equipment required to perform the tasks in this scope of work are listed below. This list is not inclusive and additional equipment may be used. All equipment used will be listed in a scientific notebook.

- Standard field hand tools including hammer, compass, feeler gauge, measuring tape, lupe, Global Positioning System (GPS), and camera[LBNL, USGS]
- Balances*[LBNL]
- Temperature and relative humidity monitoring probes*[LBNL]
- Pressure transducers*[LBNL]
- Evaporation monitoring[LBNL]
- Drilling and coring equipment
- Data acquisition systems[LBNL]
- Psychrometers*[LBNL]
- ERPs[LBNL]
- Mass flow controllers*[LBNL]

* Requires calibration

5.2 LABORATORY EQUIPMENT

The laboratory equipment required to perform the tasks in this scope of work are listed below. This list is not inclusive and additional equipment may be used. All equipment used will be listed in a scientific notebook.

- Helium Pycnometer[LBNL]
- Microscope and graticle[LBNL]
- Permeameter[LBNL]
- Pumps[LBNL]
- Psycrometers*[LBNL]
- Tracer or Dyes[LBNL]
- Resistivity meter*[LBNL]

* Requires calibration

Chemical and isotope analysis will be performed by the USGS. The equipment required to perform the tasks in this work scope by USGS are listed below. This list is not inclusive and additional equipment may be used. All equipment used will be listed in the scientific notebook.

Inductively Coupled Plasma Mass Spectrometer*[USGS]

Energy Dispersive X-Ray Fluorescence Spectrometer* [USGS]

Ion Chromatograph* [USGS]

* Requires calibration

5.3 CALIBRATION REQUIREMENTS

LBNL equipment listed above that needs calibration and assigned requirements are as follows:

- Balances will be calibrated internally following OSTI-LBNL-TIP/HT-5.0, *Balance Calibration*
- Temperature/Humidity Probes by Vaisala, Inc., calibrated annually by Bechtel Nevada Standards and Calibration Laboratory (BNSCL)
- Pressure transducers (barometric pressure transducers and permeability equipment) will be calibrated every year by BNSCL
- Psychrometers calibrated internally (TIP to be developed)
- Mass flow controller by Sierra, calibrated annually by BNSCL

- Resistivity meter calibrated annually by BNSCL (KEITHLEY 2750 or equivalent)

USGS equipment will be calibrated according to applicable YMP-USGS technical procedures identified in Table 5 or developed as needed according to S&T-QMP-5.02, *Development & Maintenance of Quality Management Procedures.*

6. RECORDS

All data will be recorded manually in scientific notebooks and associated supplemental binders, equipment logbooks, or in electronic files, including data files originating from the automated data acquisition equipment. The OSTI-LBNL generated data will be submitted in accordance with OSTI-LBNL-QIP-SIII.3, *Submittal and Incorporation of Data to the Technical Data Management System.* The USGS data will be controlled in accordance with S&T-QMP-SIII.03, *Data Collection and Review.*

OSTI-LBNL test records and other records generated as a result of implementing procedures listed in Section 4 will be collected and submitted to OCRWM by LBNL in accordance with OSTI-LBNL-QIP-17.0, *Records Management.* USGS test records will be managed in accordance with S&T-QMP-17.01, *QA Records Management*.

7. QUALITY VERIFICATIONS

No quality assurance verifications, other than regularly scheduled audits and surveillances, are required during the execution of this TWP.

8. PREREQUISITES, SPECIAL CONTROLS, ENVIRONMENTAL CONDITIONS, PROCESSES, OR SKILLS

8.1 QARD APPLICABILITY

The work governed by this TWP will be performed in accordance with the DOE Office of Civilian Radioactive Waste Management (OCRWM) *Quality Assurance Requirements and Description* (QARD), DOE/RW-0333P.

8.2 PREREQUISITES

A. Prerequisite for Field Work
Access to an analogue facility
Support for instrument calibration services
Support for drilling/coring services

B. Prerequisite for Modeling
None

C. Prerequisite for Laboratory Work
Laboratory standards

D. Prerequisites for Final Report

LBNL data that are to be used as input for reports shall be submitted to the TDMS in accordance with OSTI-LBNL-QIP-SIII.3, *Submittal and Incorporation of Data into the Technical Data Management System*. USGS data that are to be used as input for reports shall be managed according to S&T-QMP-SIII.03, *Data Collection and Review*.

8.3 SUPPLEMENT V APPLICABILITY

For the work conducted by LBNL and USGS, the electronic management of information will be controlled under the OSTI-LBNL-QIP-SV.0 and the USGS Supplement V protocols as described in Section 2.1.2. Additional controls on electronic data storage and transfer shall be documented in scientific notebooks or implemented per applicable technical procedures.

8.4 ENVIRONMENTAL CONTROLS

The scientific investigation described within this TWP will be performed at LBNL and the USGS, and at an undetermined field site. Appropriate personal protection equipment will be used in fieldwork and in the laboratory. The information collected in the field will be documented in a scientific notebook. Samples will be collected, labeled, and preserved to avoid contamination and maintain sample integrity as specified in OSTI-LBNL-QIP-SII.0 and S&T QMP-SII.01.

8.5 SPECIAL TRAINING/QUALIFICATION REQUIREMENTS

Training will be conducted for LBNL and USGS personnel in accordance with OSTI-LBNL-QIP-2.0, *Indoctrination and Training of Personnel*, and S&T-QMP-2.01, *Training of Personnel*, respectively. All individuals performing work that affects quality are required to be familiar with applicable procedures identified in Section 4.0.

Personnel qualifications for LBNL and USGS staff members will be documented in accordance with OSTI-LBNL-QIP-2.1 *Establishment and Verification of Required Education and Experience of Personnel*, and S&T-QMP-2.02 *Personnel Qualifications*, as applicable.

9. SOFTWARE

Software expected to be used will predominantly be obtained from the Yucca Mountain Project (YMP) Software Configuration Management (SCM) that has been qualified in accordance with applicable YMP procedures. Any newly developed or modified existing software will be qualified in accordance with OSTI-LBNL-QIP-SI.0, *Software Management* or S&T-QMP-SI.01, *Software Management*, as appropriate. See Table 6 for a list of YMP qualified software determined thus far to be used. In addition, LABVIEW Version 6 (National Instruments, Inc.) and Keithley Excelinx Version 1A, will be used for data acquisition and test equipment control, and routines developed will be qualified per OSTI-LBNL-QIP-SI.0.

Table 6. Qualified Software

Software Name	Version	Software Tracking Number
iTOUGH2 (and TOUGH2 – contained within iTOUGH2)	5.0	10003-5.0-00
T2R3D	1.4	10006-1.4-00
GSLIB Module SISIM	1.203	10001-1.0MSISIMV1.203-00
GSLIB Module SISIM	1.204	10397-1.0SISIMV1.204-00
GSLIB Module GAMV2	1.201	10087-1.0MGAMV2V1.201-00
GSLIB Module GAMV3	1.201	10398-1.0GAMV3V1.201-00
EarthVision	5.1	10174-5.1-00
AddCoord	1.0	10355-1.0-00
MoveMesh	1.0	10358-1.0-00
AddBound	1.0	10357-1.0-00
Perm2Mesh	1.0	10359-1.0-00
CutNiche	1.2	10356-1.2-00
CutNiche	1.3	10402-1.3-00
CutDrift	1.0	10375-1.0-00
AddBorehole	1.0	10373-1.0-00
EXT	1.0	10047-1.0-00

New software may be developed or acquired in this study. Software may be used prior to qualification to develop a preliminary output. The preliminary output will be documented and controlled by LBNL and USGS in accordance with OSTI-LBNL-QIP-SIII.3 or S&T-QMP-SIII.03, respectively. The final output shall be produced with baselined software in accordance with OSTI-LBNL-QIP-SI.0 or S&T-QMP-SI.01, as appropriate. See Table 7 for a list of unqualified software known at this time that will be used.

Table 7. Unqualified Software

Software Name	Version
Stereonet	Version 1.2.0
Labview	6
Keithley Excelinx	1A

Additional data acquisition and equipment control software may be identified, developed and used. All software-related activities performed by LBNL and USGS will be documented and controlled in accordance with the requirements of OSTI-LBNL-QIP-SI.0 and S&T-QMP-SI.01, respectively.

Data reduction, spreadsheets, and graphic presentation of data using commercial off-the-shelf software programs (e.g., Microsoft Excel 2000) may be used to synthesize, summarize, or graphically present data. The computation shall be documented such that the results can be independently reproduced or checked by hand. This software use is considered exempt from the requirements of OSTI-LBNL-QIP-SI.0 or S&T-QMP-SI.01, provided that sufficient information is included in a scientific notebook or the report documenting the operations used to calculate the contents of each cell.

10. ORGANIZATIONAL INTERFACES

DOE OSTI personnel will review the annual reports and provide input, as appropriate. The Principal Investigators from the LBNL and the USGS will coordinate on test-related design, criteria and parameters to accomplish the work described in this TWP.

LBNL shall request and coordinate with the DOE Office of Quality Assurance to conduct audits of the LBNL and USGS OSTI activities as described in OSTI-LBNL-QIP-18.0, *Quality Assurance Audits and Management Assessments*.

11. PROCUREMENT

Subcontracts for drilling and sampling are anticipated to be needed for the sampling activity described in Task 2 of this TWP. Drilling is expected to be sole source, and have a duration of up to several months. Drilling work is not quality affecting, however the analysis of drill cuttings and retrieved core is quality affecting and must be performed by qualified LBNL or USGS personnel with experience in core logging. Purchases for new and replacement items (i.e., sensors, data loggers, sample collectors) will be made through OSTI-LBNL-QIP-4.0, *Procurement Document Control*, or S&T-QMP-4.01, *Procurement Actions*, as appropriate.

12. REFERENCES

Houseworth, J.E., Finsterle, S.A., and Bodvarsson, G.S., 2003, Flow and Transport in the Drift Shadow in a Dual-Continuum Model. J. Contam. Hydrol. 62–63, 133–156.

S&T-USGS-SIP-03 *Testing the Concept of Drift Shadow*, USGS, 2004